passive solar space heating

In designing for passive solar energy use in Alaska, four major design elements can be considered:

1. South-facing windows.
2. Thermal mass.
3. Thermally insulating shutters (night insulation).
4. Building insulation (thermal performance of the structure).

Passive design implies that these building elements enable the *building itself* to function as a solar collector, instead of adding solar collectors to it. The thermal energy is transferred by natural energy flows (conduction, convection, and radiation), rather than being pumped to a point of use. Passive design techniques, involving the four elements mentioned, were described briefly in the solar technology section. The value of double, triple, or quadruple south-facing glazing has been demonstrated in a study by Aspnes and Zarling (1979). They showed that if R-9 shutters (or shutters of a higher R-value) are used, then south-facing windows in Anchorage need only be double pane to yield a net energy gain every month of the year. Nearly the same result is true for Fairbanks, except that December is the only month during which a net loss of energy occurs. Windows of east or west orientation should either be shuttered or have at least triple-pane glazing. North windows should be avoided if possible, because of their net loss for six months of the year (with or without shutters). If they are present, they should be shuttered.

The usefulness of thermal storage in the far North has long been controversial. The changes in solar gain are rapid and dramatic throughout the year, so that the amount of storage cannot be appropriately sized for more than a small portion of the year. However, because of the ever-changing, dynamic nature of solar energy and the effects it has on a building, we cannot easily separate out elements of the design to analyze them individually.

The building characteristics used in the computer study are listed in Table 10A. These are the building characteristics of a well built, modern home with good air leakage control. To determine the benefits of the four passive elements, their effect on building performance was tested using the computer model. The simulation was begun with the characteristics of the standard house. First, the south-facing glazing was varied and plotted as a ratio of the glazed area to the floor area. For instance, if the floor area is approximately 966 ft^2 (does not include second story), then 96 ft^2 of window area would be plotted as a ratio of 0.1 (10 percent) on the resulting figures (Figures 61 and 62).

Night Insulation (Shutters)

The first result of interest is shown in Figure 61. This figure indicates clearly that **any increase in shuttered or unshuttered window area for the home is always going to result in worse thermal performance of the building in December.** December is, of course, the worst solar month at high latitudes. Since glazing (even if shuttered) is a poorer insulator than the standard house or superinsulated wall sections, the thermal performance of the building in December always gets worse with increasing window area. This demonstrates the worst case for an average year. **The only way to overcome such an effect would be to ensure that the insulating value of the shuttering device is equal to that of the walls.** This is difficult to do, but it is a technical problem worth pursuing. It is

TABLE 10A: A LISTING OF PARAMETERS FOR THE TRNSYS COMPUTER MODELING USED TO FIND AN OPTIMUM PASSIVE SOLAR DESIGN FOR FAIRBANKS, ALASKA

1. Window-triple pane: U = 0.34 BTU/hr•ft$^{2.0}$F, Area 0 to 300 ft^{2}, R = 2.94
2. Infiltration: 0.15 air changes per hour
3. Thermal capacitance: C=4000 to 16,000 BTU/^{0}F
4. Insulation: As given in Table 7B
5. Ground reflectance: varied from 0.2 during fall and spring to 0.6 during winter
6. Thermal shutters: U = 0.125 BTU/hr•ft$^{2.\ 0}$F, operated on an open cycle between 7:00 a.m. and 8:00 p.m. R = 8
7. Shading: Two-foot wing walls and overhang with one-foot perimeter gap
8. Allowable temperature swing: 65^{0}F to 78^{0}F
9. Ventilation fan turned on whenever interior temperature exceeded 78^{0}F
10. Transmittance of windows: Assumes a transmittance of 0.70 at normal incidence
11. ASH RAE response factors for light and medium weight construction
12. Internal generation: 750 watts

also worth noting that thermal mass provided no benefits during this simulation. Varying the amount of thermal mass by a factor of 4 did not affect the December heating load.

Analysis Of Parameters

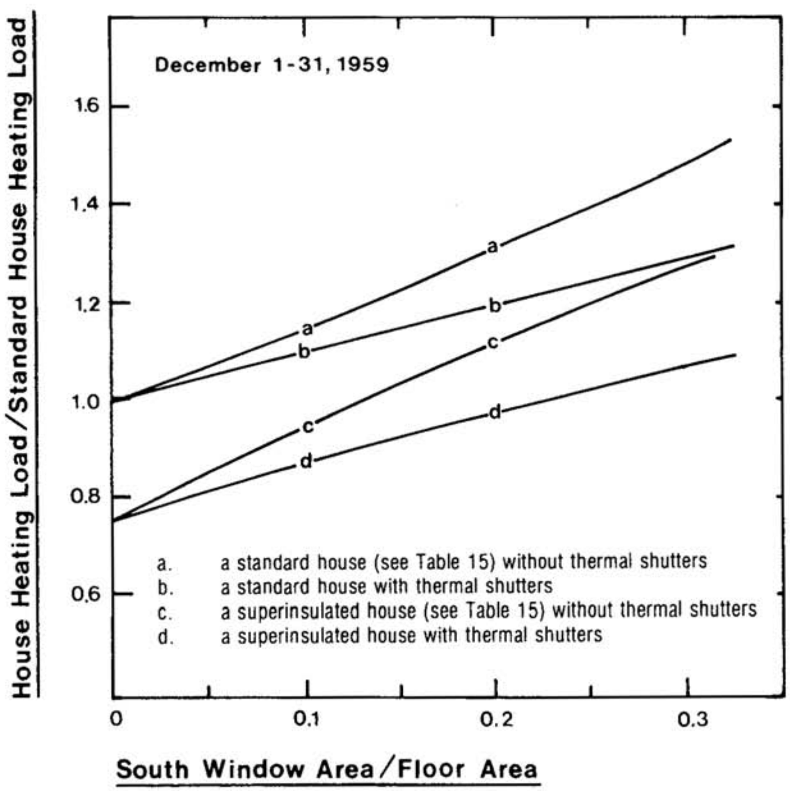
Figure 62 shows the results of varying all the parameters in cumulative fashion to arrive at the best possible performance of a passive structure, which combines superinsulation, added internal mass, and an area of south-glazing with shutters, for a heating season from September through May. The first curve, labeled "a," traces the performance of a typical house (as defined in Table 10B) as unshuttered window area is increased. Thermal performance increases somewhat until the ratio of window area to floor area reaches 0.1; then the performance declines as the heat loss from the increasing window area gradually cancels the benefits from solar gain through those same unshuttered windows. Curve "b" is a case similar to curve "a" except that the internal mass is doubled. This results in an optimum performance for this house at a window area to floor area ratio of 0.2, or 20 percent. **The added mass, therefore, enables the performance of this house with south-facing, unshuttered windows to be improved by approximately 1 percent of the annual heating requirements (from 0.94 to 0.93 of the house's requirements).**

Curve "c" dramatically indicates the effect of shutters on a passive solar structure. With the shutters, the south-facing window area of a standard structure can be increased to 30 percent of the floor area before the heat loss of that shuttered area begins to cancel the solar gain. Shuttering the windows on a standard home can result in up to a 22 percent reduction in required heating, as indicated from this modeling process, and depending on the south-facing window area as well as other window orientations and shuttering cycles. A shuttering cycle is the daily pattern of opening and closing the shutters on a structure. For example, open at 7 a.m., closed at 8 p.m., open at sunrise, closed at sunset, etc.

Curve "d" shows the combined effect of shuttering the windows and doubling the interior mass. The effect of the additional mass is similar to that of curve "b"; it is a small, additive effect, totaling 4 percent of the total standard house heat

TABLE 10B: SPECIFICATIONS FOR THE WALL AND ROOF SECTIONS USED TO COMPARE A STANDARD HOUSE TO A SUPERINSULATED HOUSE

Standard House			Superinsulated House		
Wall Sections	**U-Value**	**R-Value**	**Wall Sections**	**U-Value**	**R-Value**
Inside air film 5/8 in. gyp board 5-1/2 in. fiberglass 1/2 in. plywood 7/8 in. cedar siding Outside air film	0.047	21.3	Inside air film 5/8 in. gyp board 11 in. fiberglass 1/2 in. plywood 7/8 in. cedar siding Outside air film	0.025	40
Inside air film 5/8 in. gyp board 5-1/2 in. Douglas Fir 1/2 in. plywood 7/8 in. cedar siding Outside air film	0.100	10	Inside air film 5/8 in. gyp board 7 in. Douglas Fir 4 in. fiberglass 1/2 in. plywood 7/8 in. cedar siding Outside air film	0.040	25
Roof Sections	**U-Value**	**R-Value**	**Roof Sections**	**U-Value**	**R-Value**
Inside air film 5/8 in. gyp board 11-1/4 in. fiberglass 5/8 in. plywood Felt paper Asphalt shingles Outside air film	0.025	40	Same as for standard house	0.025	40
Inside air film 7/8 in. gyp board 1-1/4 in. Douglas Fir 5/8 in plywood Felt paper Asphalt shingles Outside air film	0.062	16.13	Same as for standard house	0.062	16.13



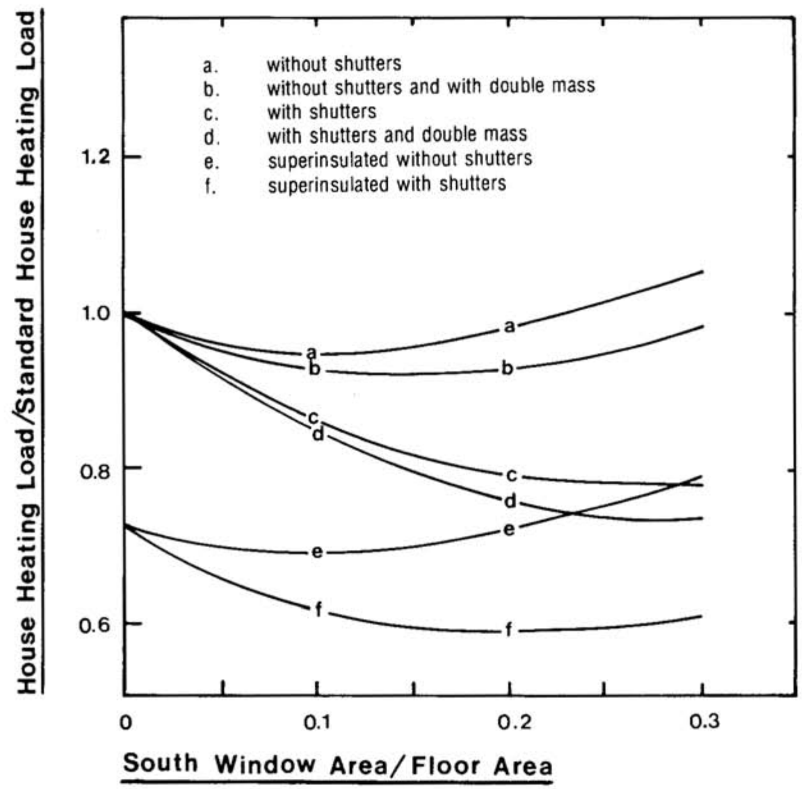


Figure 61. Increasing the window area of a structure to improve solar gain always results in increased heat loss for the month of December.

Figure 62. Annual heating requirements for houses with and without thermal shutters and various amounts of south-facing windows.

load at a window area to floor area ratio of 0.30 (30 percent).

Curve “e” shows the performance of the unshuttered, superinsulated house. It is identical in shape to curve “a,” but demonstrates the lower energy consumption afforded by the additional insulation. Otherwise, the unshuttered windows cause the same increase in heat loss as in case “a.” Curve “f” is an example of an optimum passive solar design. It shows the results of the computer simulation of the superinsulated home (see Table 10B) with shutters operated on a 7 a.m. open—8 p.m. closed daily cycle. **The best-performing structure is a house with a south-facing glazed area equal to 20 percent of the floor area, lightweight construction (no additional thermal mass), shutters, and superinsulation.**

The most crucial insight to be gained from this result of the analysis of passive solar gain, is the overwhelming importance of energy efficient, energy-conserving design of the building. This is most clearly shown by curves “e” and “f” in Figure 62.

These last two curves start with this energy-conserving house, and clearly show that **everything done to the standard house to improve its passive solar performance doesn’t get you to the 25% heat load reduction which you start with in a superinsulated design!**

COMPUTER SIMULATION

(Editor’s note: these are an update for the second edition).

The following list of solar simulation programs is from U.S. Department of Energy efforts, and all are limited to PC/Windows platforms. For a Macintosh-compatible simulation tool, see the Canadian RETSCREEN option below.

Energy Simulation Software

Data from energy simulation software can be very helpful to the design process. It helps architects and building designers quickly identify the most cost-effective, energy-saving measure for commercial buildings. A partial list is shown below; a comprehensive database of simulation products can be found on the website: www.eren.doe.gov/buildings/highperformance/simulation_ software.html

ENERGYPlus—A new-generation building energy simulation program from the creators of BLAST and DOE-2.

ENERGY-10—ENERGY-10 is an award-winning PC-based design tool that helps architects and building designers quickly identify the most cost-effective, energy-saving measures for small commercial and residential buildings.

RADIANCE—RADIANCE is UNIX freeware for lighting design and rendering, developed by the U.S. Department of Energy and the Swiss federal government.

DOE-2—An hourly, whole-building energy analysis program that calculates energy performance and life-cycle cost of operation.

Software Overview (for Macs)

Renewable energy technology (RET) projects are not routinely considered by planners and decision-makers at the critically important initial planning stage. The RETScreen® Renewable Energy Project Analysis Software has been developed to help address this barrier.

(continued on next page)

RETScreen International is a renewable energy awareness, decision-support, and capacity-building tool developed by the CANMET Energy Diversification Research Laboratory (CEDRL) with the contribution of over 89 experts from industry, government, and academia. The core of the tool consists of a standardised and integrated renewable energy project analysis software that can be used world-wide to evaluate the energy production, life-cycle costs, and greenhouse gas emission reductions for various types of renewable energy technologies (RETs). Each RETScreen renewable energy technology model (e.g., Solar Water Heating Project, etc.) is developed within an individual Microsoft® Excel spreadsheet "Workbook" file. The Workbook file is in turn composed of a series of worksheets. These worksheets have a common look and follow a standard approach for all RETScreen models. In addition to the software, the tool includes product, weather, and cost databases; an online manual; a website; project case studies; and a training course. RETScreen is also convertible to a Macintosh platform, which can be done through instructions at the website: http://retscreen.gc.ca/ang/d_o_view.html

The lesson couldn't be more clear from this example: build a very well insulated structure first, and then add the passive solar features and shutters.

Several other instructive conclusions for passive solar design of light-construction buildings at subarctic latitudes can be drawn from the preceding study:

1. Triple-pane, south-facing windows yield a modest energy savings of 6 to 8 percent if the window-to-floor-area ratio is in the range of 0.1 to 0.2. Windows facing any other direction will experience a net loss of thermal energy over the heating season.
2. Thermal shutters as modeled in this study on all south-facing windows of the structure can supply up to 22 percent of the space heating requirement. Of course, these savings are dependent on the open-close cycle and the insulating value of the shutters. If higher R-value shutters with a shorter open cycle are used, additional savings would be realized. One of the most attractive retrofits for existing homes is thermal shutters. A need exists for a well-designed, low-cost, semiautomatic shutter for old as well as new construction. Ideally, a shutter system would open only during periods of useful solar energy gain, but this is likely to be objectionable on aesthetic grounds. Also, the shutter would perform best if its insulating value were equal to that of the surrounding superinsulated wall. Size and mobility requirements for shutters preclude this.
3. Superinsulated construction combined with direct-gain, passive solar techniques have an additive effect, resulting in a 25 to 40 percent reduction in the annual heating load.
4. Increased thermal mass in a structure can produce energy savings. However, at high northern latitudes with severe winters and little midwinter sun, these savings are not dramatic, and are unlikely to warrant the added expense of their inclusion in the structure.

Highly insulated structures are gaining popularity as the logic and comfort of such homes become obvious, even though the extra wall thickness adds to the initial cost of the building. Insulation costs are directly proportional to thickness and labor costs for framing increase, as are the costs of windows and doors with their required jam extensions. However, much progress has been made in integrating many of these solar, conservation, and health features into modern housing.

The Problem Of Thermal Shutters

Windows are notoriously poor thermal insulators and usually are a major source of heat loss in structures. Insulating windows can significantly reduce this heat loss. A double-pane window with an R-value of 1.84 loses heat at the rate of 0.54 BTU/hr/ft^2/°F. A wall with an R-value of 19 loses heat at a rate of 0.05 BTU/hr/ft^2/°F. Thus the window loses about ten times more heat per unit area than the wall under the same conditions. Obviously, when windows are not gaining useful heat during the dark period of the day, they are rapidly losing heat to the environment if it is colder outside than inside the structure. So windows need to be insulated at night if they are to perform optimally in a passive solar design.

What kind of shutter (also called movable insulation and night insulation) should you use? There are indoor shutters, outdoor types, shutters that fit into a wall pocket, shutters that fold away into a storage area, shutters that open and close automatically, and shutters that are controlled by photoperiod. There are R-2 shutters and R-15 shutters. But there are no ideal shutters. Every design has liabilities. They must open and close, be reliable in the most extreme conditions Alaska can offer, and—perhaps most important of all—they must be **used.** If shutters are bothersome, unaesthetic, or unreliable in operation, they will be discarded or avoided. We do not yet have the technology for ideally coupling night insulation with south-facing glazing for passive solar design. Alaskans should continue working to find a better shutter design for our homes (see Figure 63.)

One of the questions often asked about shutters concerns their position relative to the window. Should the shutter be placed outside the window or inside? The answer is not simple, because neither solution is trouble-free. Placing the shutter mechanism outside exposes it to weather and reduces the ease of operation. The shuttering mechanism can become frozen open or shut from ice buildup, especially if it is a track or hinged mechanism. Any cranks or levels that penetrate the wall can also ice up due to freezing condensation; they also conduct valuable heat through the wall. If these types of mechanisms aren't used, then one must operate the shutters from outside, an unappealing option at –40°F.

Figure 63. The superinsulated, straw-bale, solar optimal home of Kevin Maxwell, which has operable (with steel cable/pulley system) ~R-30 shutters which open vertically upward on hinges as shown in this April 2005 photo.

Placing the shutter on the inside of the window **may** work, but it has similar problems. Interior shutters are convenient since they can be operated from inside the building, but this strategy causes the inside window surface to become colder. If the shutter is not sealed to exclude the passage of warm moist interior air to this cold window, one or all of the following will happen:

1. Water will drip down the sills of the window, along the wall, and onto the floor, discoloring and decaying the building materials.
2. Water will freeze behind the shutter, icing over the window and limiting its usefulness when unshuttered. When it **is** unshuttered, the ice will melt and repeat the events described above.
3. The shutter will freeze in place until a thaw comes.

Sealing the shutter from vapor problems is possible, but not simple, and most commercially available shutters do not have vapor seals. This discussion reflects the situation with window shutters in the early 1980s, at the first printing of this manual. The situation in 2005 is regrettably little improved regarding night insulation. What have improved are window technologies such as vacuum glazing and heat mirror® products. These options in no way approach an optimum U-value however (U = 1/R-value.)

Effects Of Climate

The continental Alaska climates are typically characterized by long, cold winters and short, relatively warm summers. Solar radiation varies with the seasons, due to both the seasonal solar elevation angle and day length and seasonally changing humidity. In Alaska, this can be seen by investigating the average solar radiation on a south-facing vertical surface. Figure 64 shows the comparison of two related quantities: the monthly average heating index, and the average daily solar radiation (BTU/ft^2) on a south-facing vertical surface in Fairbanks. Figure 65 shows the same comparison for the Matanuska Valley of Alaska, and Figure 66 for Bethel.

In the examples, an important and somewhat unexpected pattern is evident. Intuitively, the average solar radiation on a south-facing vertical surface (or any surface) should be symmetrical in magnitude about the summer solstice. One expects the average solar radiation in September to be very nearly equal to that in March. However, at Bethel, Matanuska, and Fairbanks, the solar radiation in March averages twice as much as that in September, on a vertical south-facing surface. The asymmetry is due to late summer and autumn cloudiness, the presence of high-albedo snow in spring, and predominantly clearer weather during the period from February through May. The result is that solar radiation on a south-facing vertical surface (the most important consideration for passive solar design) is out of phase with heating degree-days. Solar gain peaks in March and April, when the solar heat is still very useful. The solar geometry and climate provide an unexpected benefit for passive solar applications in the far North.

As in the case of active solar applications, the presence of snow cover for up to six months of the year is a positive factor, improving the effectiveness of passive solar energy in Alaska.

Performance Of "Classic" Passive Designs In Alaska

As in many fields of design, passive solar technology has "classic" types. There are (1) direct gain systems, primarily using glazing and thermally efficient structures; (2) Trombe wall designs; (3) greenhouse options; and (4) direct gain with thermal shutters, also referred to as "direct gain with night insulation."

These classic designs have been analyzed for their performance through a design project for a rural Alaska school, sponsored by the Alaska Department of Transportation and Public Facilities and the U.S. Department of Energy. These Alaska Department of Transportation and Public Facilities studies include:

1. *Two Rivers Passive Solar School Analysis, Interim Report*, J.S. Strandberg Engineers, Report No. AK-RD-82-18, Alaska DOT&PF, December 1981. 23 pp. plus appendices.
2. *Passive Solar Heating in Alaska*, by John P. Zarling, Report No. AK-RD-81-15, Alaska DOT&PF, June 1980, 17 pp.
3. *A Thermal Performance Design Optimization Study for Small Alaskan Rural Schools*, John Zarling and James S. Strandberg, March 1983, Report No. AK-RD-83-2, 118 pp. plus appendices.
4. *An Analytical Study of Passive Solar Energy and Mass Storage: Observations from a Test Building in Fairbanks, Alaska*, by Richard D. Seifert and George S. Mueller, Report No. AK-RD-85-21, June 1983, 50 pp. plus appendices.

Direct Gain Passive Solar Design

This section reviews the physical features of a structure that can influence the performance of a direct gain system.

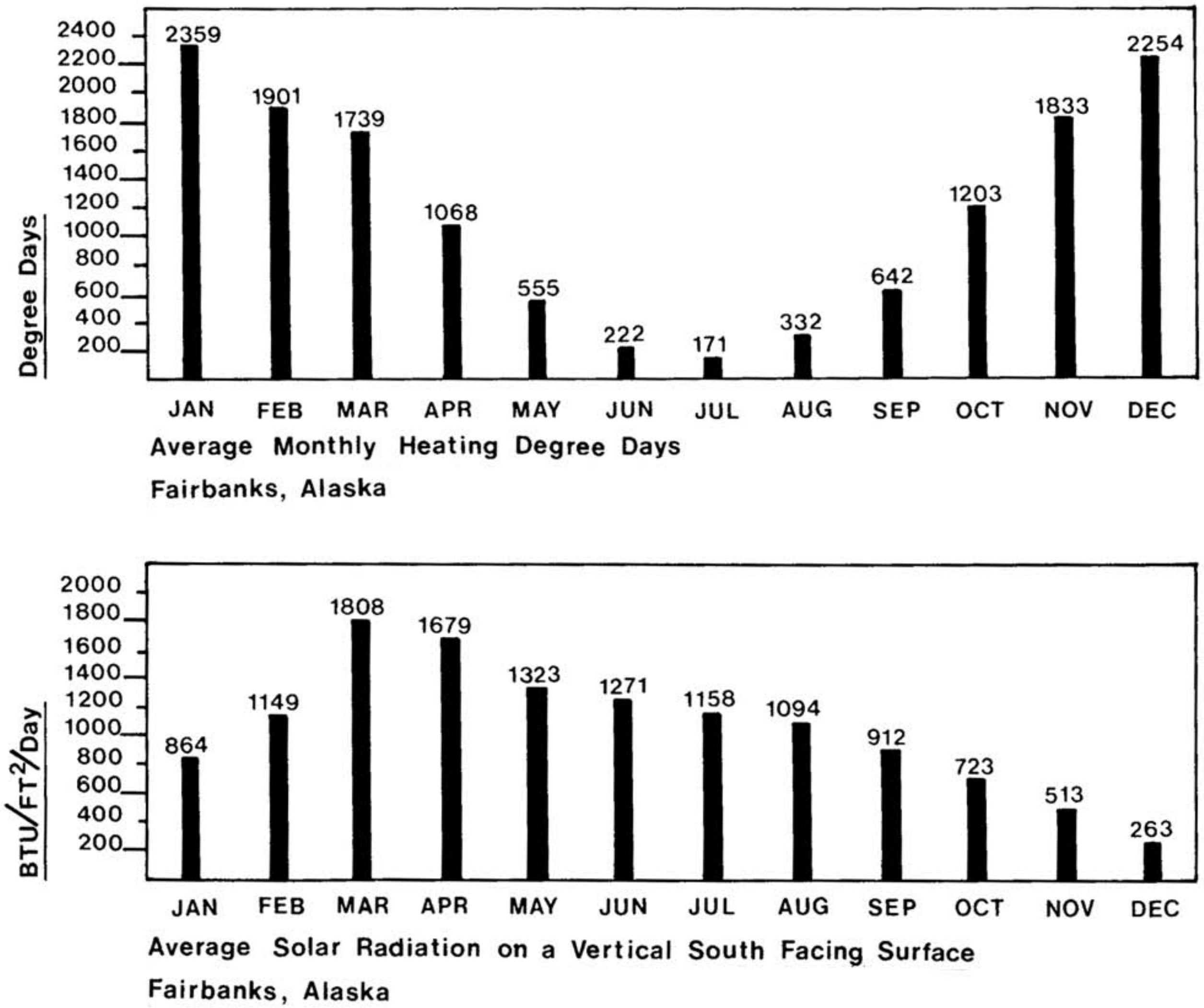
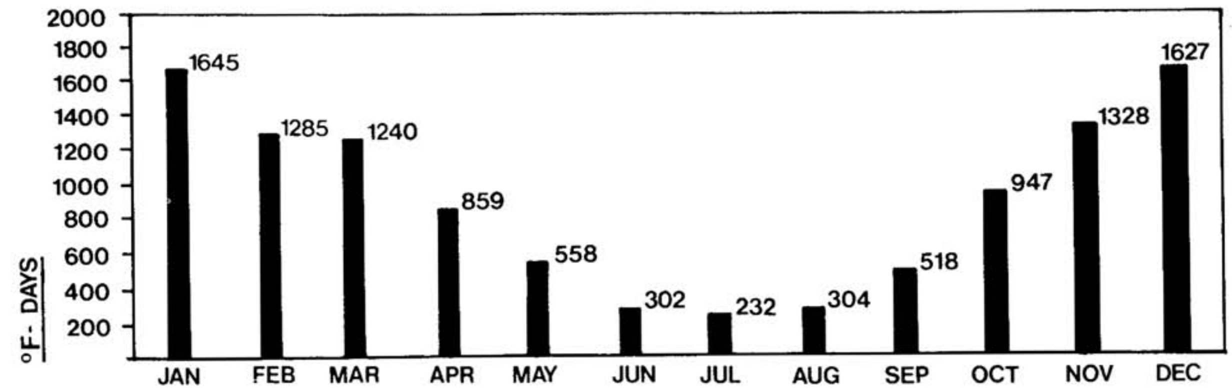
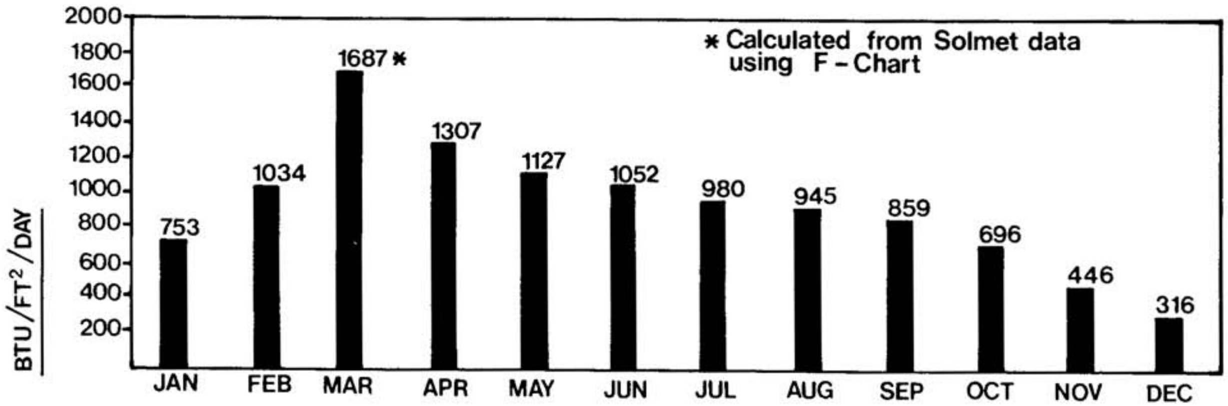


Figure 64. These graphs illustrate that the Fairbanks heating degree days and average solar radiation (which are an indication of a building's heating requirements) are not in phase with the solar radiation on a south-facing vertical surface. This has positive implications for passive solar heating. The solar gain is highest in March and April, when heating is needed. Data are from Kusuda and Ishii (1977).



Average Monthly Heating Degree Days
Matanuska, Alaska



Average Solar Radiation on a Vertical South Facing Surface
Matanuska, Alaska

Figure 65. Matanuska heating degree days and average solar radiation. These graphs illustrate that the annual heating degree days (which are an indication of a building's heating requirements) are not in phase with the solar radiation on a south-facing vertical surface. This has positive implications for passive solar heating. The solar gain is highest in March and April, when heating is needed. Data are from Kusuda and Ishii (1977).

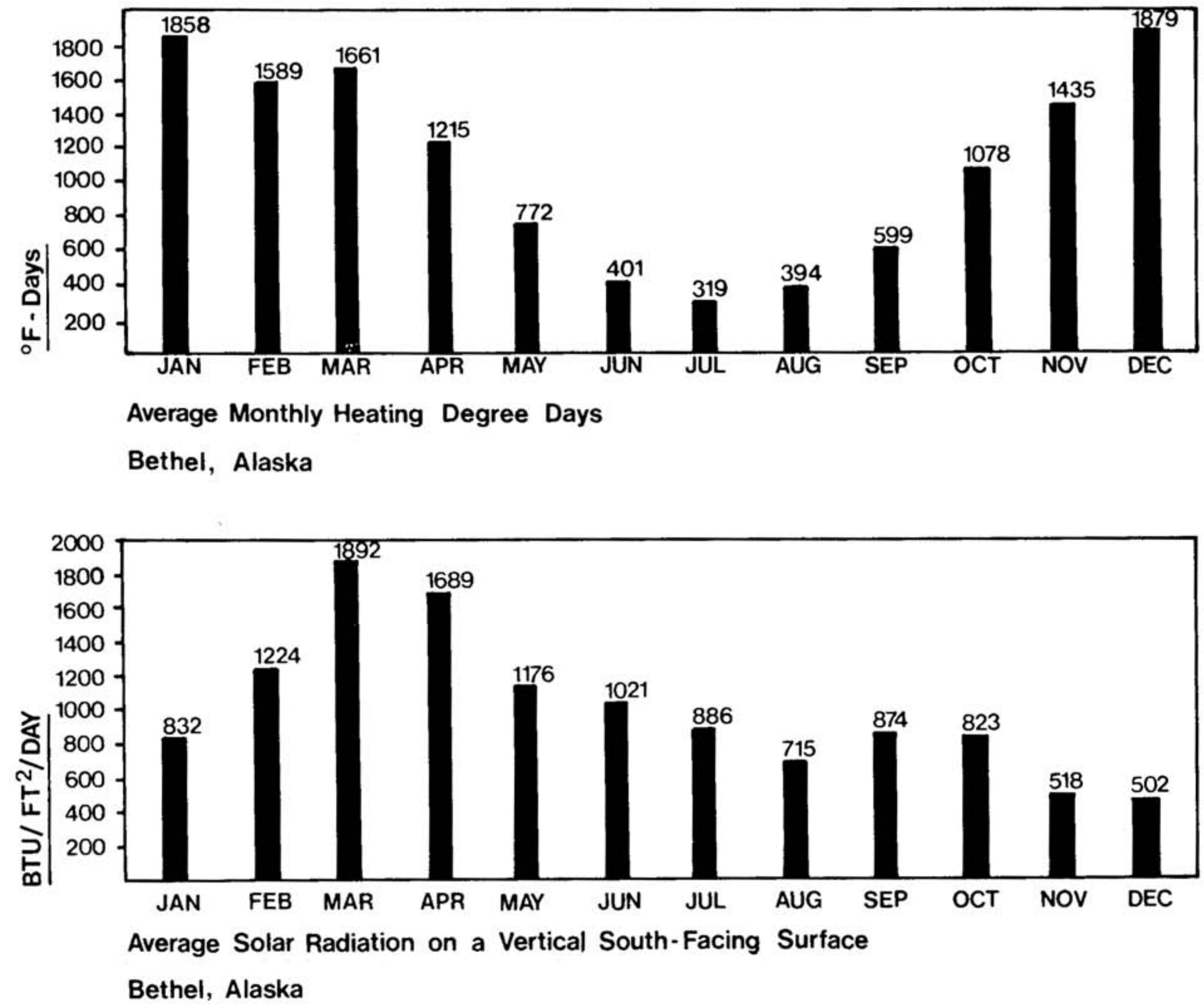


Figure 66. Bethel heating degree days and average solar radiation. These graphs illustrate that the annual heating degree days (which are an indication of a building's heating requirements) are not in phase with the solar radiation on a south-facing vertical surface. This has positive implications for passive solar heating. The solar gain is highest in March and April, when heating is needed. Data are from Kusuda and Ishii (1977).

It prepares the user for an actual Alaska passive solar design calculation.

Absorptance

The solar absorptance, α, of internal walls and furnishings may be a significant design feature in raising or decreasing the comfort level in a structure. Too much absorptance, and a building can become too hot. Too much reflectivity, and the building won't absorb enough heat. Although darker colors are more absorptive, they also become very hot when exposed to direct solar radiation for extended periods of time. The use of a direct gain space must be carefully considered. A dark metal surface with a small amount of mass can reach temperatures in the range of 120 to 140°F. Substances with absorptivities of 0.5 to 0.7 will still get very warm when exposed to the sun, but they reflect more of the incident solar radiation, achieving more even heating of the space. Table 11 lists the absorptances of common materials.

The following suggestions are offered as a means of assuring that absorption levels on nonmassive surfaces be kept reasonably low in direct gain zones.

1. As a general rule, massive surfaces in a direct gain zone should be relatively dark in color, and low mass surfaces should be relatively light. This arrangement encourages absorption of sunlight on surfaces where the heat can be stored.
2. If dark objects with little thermal capacity are placed in a direct gain zone, they should be located out of direct sunlight as much as possible.

Adherence to these simple rules will help eliminate overheating problems in properly sized, direct gain structures.

Lightweight objects with low heat capacity (such as furniture) can diminish the performance of a direct gain building, especially if placed in direct sunlight. However, according to work done by Balcomb et al. (1980), the penalty for absorbing 20 percent of the transmitted solar radiation directly on nonmassive surfaces never exceeds 5 percent. This information is useful to an architect or designer who needs to make choices of furniture and wall coverings in a building, especially as it affects passive solar performance. The concern is that a large amount of low-mass material in a direct gain sunspace might cause more frequent overheating and high levels of discomfort. An example of the worst-case situation is described in the next paragraph and helps to clarify that the interior design in passive solar structures is not severely constrained by the type, amount, and solar absorptance of the furnishings.

In order for half of the transmitted solar radiation to be transferred rapidly into the room air, it would be necessary for half of the exposed surface area to be a perfect absorber with no thermal storage capacity. Or, equivalently, if the surfaces lacking thermal storage capacity have a solar absorptance of 0.5, they must intercept all of the transmitted solar flux in order to transmit 50 percent of the absorbed radiation directly to the air (the air heating fraction). These two extreme cases seem to indicate that a designer would have to try very hard to design a structure that would rapidly overheat.

However, rapid overheating may still be a problem in Alaska. Since our computer simulations show that thermal mass storage is less useful for structures in Alaska, an optimum passive solar design for Alaska would more closely approach the extreme case of a perfect absorber with no thermal storage capacity. Thus Alaska designs may require ventilation systems to remove this heat.

Two strategies may help avoid overheating problems. First, use interior paints and surface materials with absorptances of 0.5 or less. This would ensure that the air-heating fraction is 50 percent or less. Second, avoid using a surface material that is a good thermal insulator, such as carpeting, especially if its absorptance is greater than 0.5. Thus,

TABLE 11: SOLAR ABSORPTANCE OF VARIOUS MATERIALS[1,2]

Optical flat black paint	.98
Flat black paint	.95
Black lacquer	.92
Dark gray paint	.91
Black concrete	.91
Dark blue lacquer	.91
Black oil paint	.90
Stafford blue bricks	.89
Dark olive drab paint	.89
Dark brown paint	.88
Dark blue-gray paint	.88
Azure blue or dark green lacquer	.88
Brown concrete	.85
Medium brown paint	.84
Medium light brown paint	.80
Brown or green lacquer	.79
Medium rust paint	.78
Light gray oil paint	.75
Red oil paint	.74
Red bricks	.70
Uncolored concrete	.65
Moderately light buff bricks	.60
Medium dull green paint	.59
Medium orange paint	.58
Medium yellow paint	.57
Medium blue paint	.51
Medium kelly green paint	.51
Light green paint	.47
White semigloss paint	.30
White gloss paint	.25
Silver paint	.25
White lacquer	.21
Polished aluminum reflector sheet	.12
Aluminized mylar film	.10
Laboratory vapor deposited coatings	.02

[1]This table is meant to serve as a guide only. Variations in texture, tone, overcoats, pigments, binders, etc., can alter these values.

[2]A perfect absorber has an absorptance of 1.00; i.e., it absorbs 100 percent of the incident solar radiation. All common materials absorb less.

for example, don't use carpets, or if you do, use light-colored carpets.

Wind Speed and Spacing of Glazing

Wind blowing across (sweeping) a window surface removes the insulating air film on the outside of the glazing. This can dramatically affect the rate of heat loss from a window. Most locations in continental Alaska have an average wind speed less than the 15 mph reference value that the American Society of Heating, Refrigerating, and Airconditioning Engineers (ASHRAE) uses as a standard for reporting film coefficients on external building surfaces. The actual film coefficient should be based on one-half of the actual recorded wind speed at a given location. Using half of the hourly wind speed to compute film coefficients on the outside surface of direct gain glazing reduces the calculated amount of heat lost from the surface and yields higher performance predictions. **For night-insulated cases the improvement is small.** However, for designs without night insulation, the fractional decrease in effective conductance of the solar wall or glazing is significant.

A gap between window panes of ¼ inch has been the traditional standard. It has been established that the air gap thickness affects the conductance of double-glazed windows, but only recently has the effect on performance of direct gain buildings been studied. Figure 67 (after Balcomb et al., 1980) shows that increasing the air gap from ¼ to ½ inch raises the solar savings by 12 to 15 percent, depending on whether or not the effect

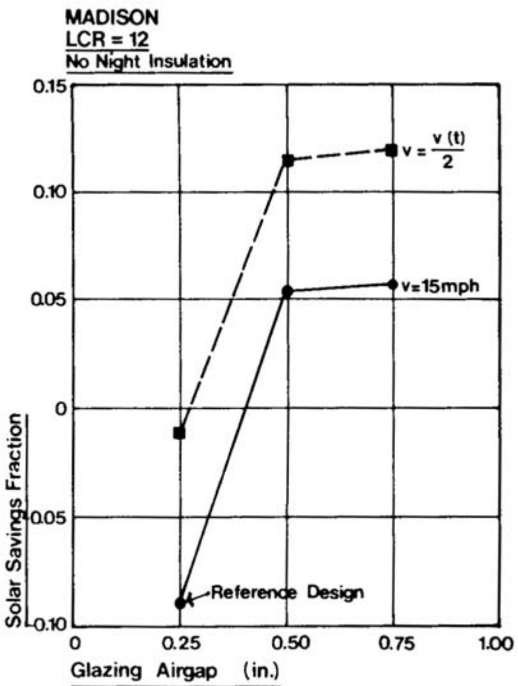


Figure 67. The effect of different values of air gaps between the double glazing layers and the effect of different assumptions of wind velocity on performance in Madison, Wisconsin (after Balcomb et al., 1980).

of variable wind speed has already been accounted for. The direct gain design that was originally a 9 percent loser now shows a positive solar savings of 11.5 percent. Further increases in air gap thickness yield very little additional improvement in performance because convection currents between the glazings negate the insulating effect of the thicker air layer. Using a glazing air gap of at least ½ inch decreases heat loss from direct-gain buildings, especially if night insulation is not used.

Effect of Overhangs

Overhangs are normally used in most passive solar applications to reduce summer overheating. If the overhang is properly designed, there is no blockage of the sun for most of the heating season, but almost entire blockage of the midsummer sun. Figures 68 and 69 show a simple, convenient scheme for determining the sun angles at noon on the summer solstice, winter solstice, and equinoxes. **Overhangs are in some ways more important in Alaska than they are elsewhere** because our lower solar angles require exaggerated overhangs to achieve the desired amount of shading. Without proper shading, overheating can begin in March and April and continue through the summer. Fortunately, however, overheating in most of Alaska can be avoided by opening windows or venting.

Note that the glazing should not extend to the bottom of the overhang because the top portion of the window would receive direct sun only in midwinter but would lose as much heat as any other part of the window.

If the overhang is in place during all of the year (fixed overhang) then the design of the angles becomes a tradeoff between a sacrifice of solar heating during the spring months (when the sun angles are high but the weather is still cold) and overheating during summer (when the sun angles are higher and temperatures are warm).

Important: Murphy's Law Of Overhangs:

"Any overhang which has a very significant effect on reducing the cooling load also has a very significant effect on reducing the solar heating contribution."

An alternative to fixed shading is movable shading (such as awnings). This is awkward and not much favored by designers, but it is quite effective. The shade can be left on until late in the fall, thus substantially reducing overheating. The shade can then be taken off and left off until late in the spring after the heating season is over.

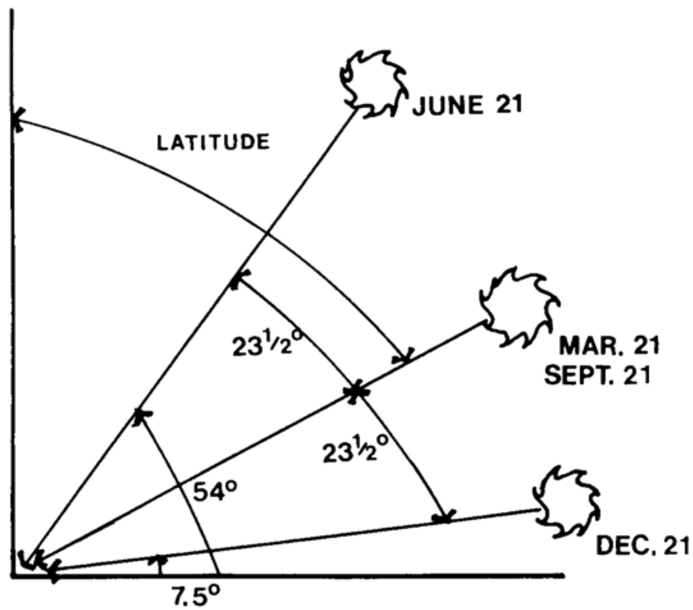


Figure 68a. The range of solar elevation angles at the latitude of Anchorage, Alaska (60°30'N). The maximum elevation is 54° on June 21, and the minimum is 7.5° on December 21.

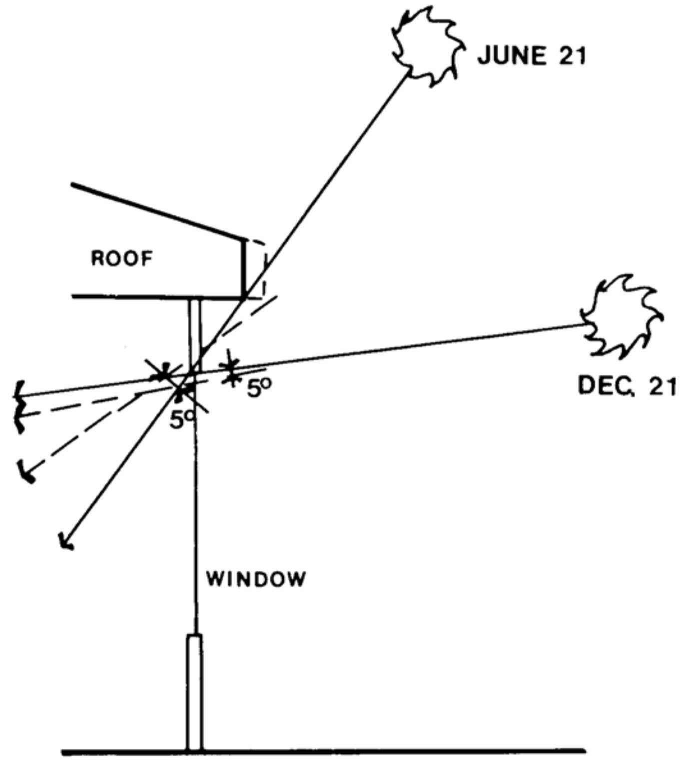


Figure 68b. Unlike the lower latitudes, a small overhang has little effect on shading the summer sun in Alaska. Larger overhangs are required in Alaska because of the lower solar elevation angles.

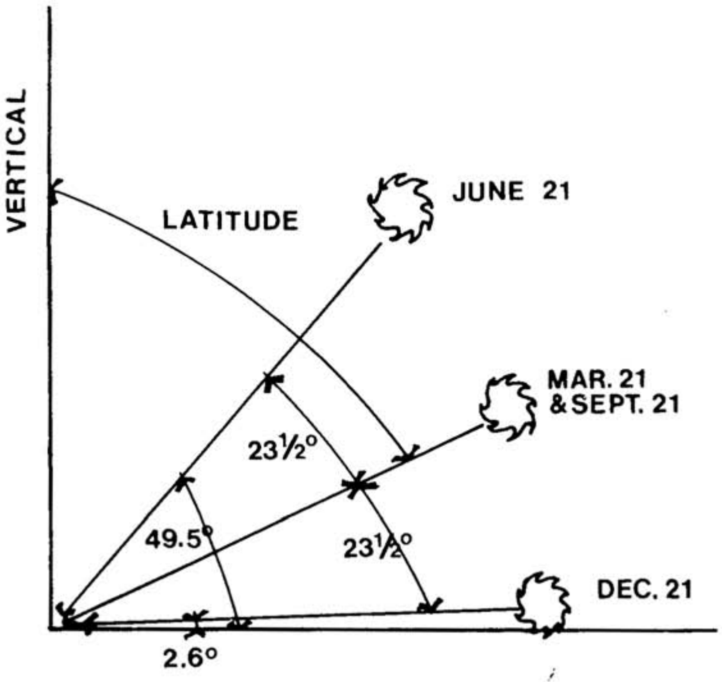


Figure 69a. The range of solar elevation angles at the latitude of Fairbanks (64°N). The maximum elevation is 49.5° on June 21, and the minimum is 2.6° on December 21.

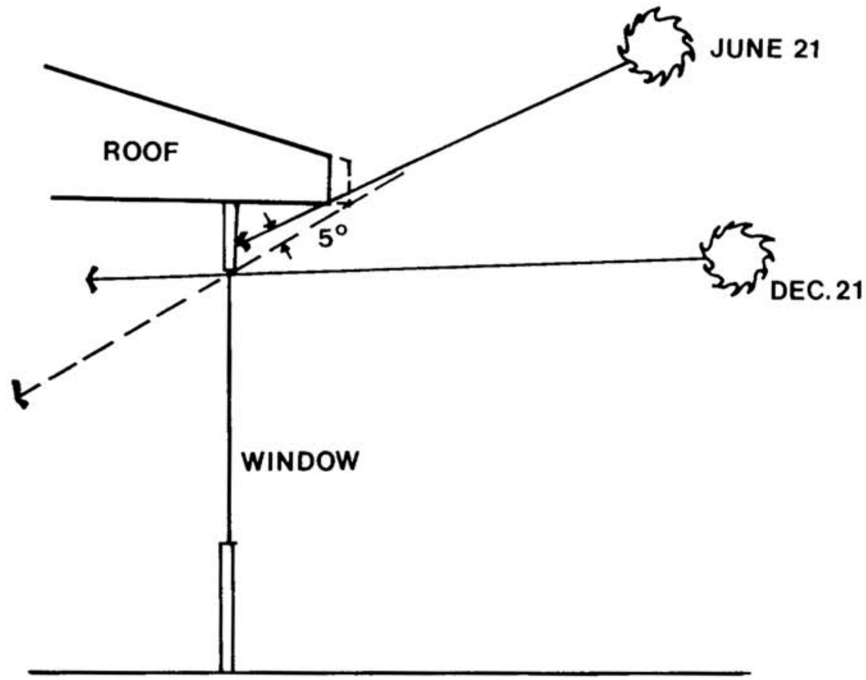


Figure 69b. Like Anchorage (Figure 62b), a small overhang in Fairbanks will not significantly alter summer solar gain on a window. A larger overhang is necessary because of the lower solar elevation angle.

Another option is to use night insulation as shading. It allows a very simple and effective means of accommodating to the weather; it markedly improves performance during the winter and is especially effective at reducing summer overheating. Types of night insulation that are located outside the window are particularly effective for summer shading. If they are located inside the window, the designer must be particularly careful to avoid material damage associated with buildup of heat between the glazing and the insulation by using a light-colored or reflective outer surface. Thermal stress breakage of glazing can also be a problem. Use of tempered glass will help reduce the likelihood of this occurring.

Effect of Ground Reflectance

The effect of ground reflectance on the performance of solar energy systems was mentioned previously in this manual (see section on active solar water heating). There is little doubt that the increased ground reflectance due to snow cover contributes significantly to useful solar radiation during the winter season at high latitudes. Willcut et al. (1975), in a study of Canadian locations, found that ground-reflected solar radiation can contribute 8 percent of the total annual usable energy. In Alaska, this fraction may be even higher because of the longer duration of snow cover and lower sun angles, causing more solar radiation to be reflected onto solar collection surfaces. Tables 12 and 13 show the reflectivity values for fifteen different surface characteristics and twelve representative winter landscapes, respectively.

Estimating The Building Load Coefficient

The first step in the process is potentially difficult: obtaining an estimate of the thermal load of the building, even before the design is final. Accepted procedures that predict the heating load of buildings are described in the 1977 *ASHRAE Handbook of Fundamentals*. Given detailed knowledge of the building geometry and construction, they provide comprehensive estimates of each element of the heating load. They are customarily used during the construction documents phase of the design, to accompany detailed drawings and specifications.

This procedure provides little help to the designer during the design development phase of a project. It has two failings:

1. Detailed specifications of the building are not known. Windows have not yet been precisely sized, wall construction details have not yet been firmed up, and exact wall areas and building volumes are not yet known. Thus the input information required for a detailed design load calculation is unknown.
2. Few designers would take the time to go through this involved calculation. Design development is an iterative process, and a much faster procedure is needed if it is to be used.

Quick and Dirty Heating Load Estimate

Therefore, there is a need for a "quick and dirty" method for estimating heating load. The procedure should take into account the important gross characteristics of the building that have been established before design development. These characteristics are the building gross floor area and perimeter; the number of stories; the R-values of the walls and roof; whether the building is to be built with concrete slab on grade (i.e., no basement), over a basement, or over a crawl space; and a rough idea of the fraction of the wall area that will be allocated to windows.

The following procedure fills this need. It will give answers that are usually within 10 percent of the detailed ASHRAE* heating load calculation, and it will show the relative contribution of the various important factors that make up the heating load.

*American Society of Heating, Refrigerating and Air Conditioning Engineers

TABLE 12: REFLECTANCE VALUES FOR FIFTEEN CHARACTERISTIC SURFACES (INTEGRATED OVER SOLAR SPECTRUM AND ANGLE OF INCIDENCE)	
Surface	**Reflectance**
1. Snow (freshly fallen or with ice film)	.70
2. Water surfaces (relatively large incidence angles)	.07
3. Soils (clay, loam, etc.)	.14
4. Earth roads	.04
5. Coniferous forest (winter)	.07
6. Forests in autumn, ripe field crops, plants	.26
7. Weathered blacktop	.10
8. Weathered concrete	.22
9. Dead leaves	.30
10. Dry grass	.20
11. Green grass	.26
12. Bituminous and gravel roof	.13
13. Crushed rock surface	.20
14. Building surfaces, dark (red brick, dark paints, etc.)	.27
15. Building surfaces, light (light brick, light paints, etc.)	.60

In the process of calculating a heating load, a Building Load Coefficient (BLC) is determined. The primary use of the BLC is for estimating the solar savings of buildings heated by passive solar energy.

The procedure is not intended to be comprehensive, and it will not handle all situations. For example, it should not be used for underground structures. It is primarily intended for small buildings with skin-dominated loads (that is, dominated by heat loss by conduction and convection as opposed to loss dominated by air exchange, like large public buildings). It is not particularly appropriate for large buildings where the bulk of the heating energy is contributed from internal energy generation. It is by no means intended to substitute for a detailed ASHRAE heating load calculation, which should always be done during the construction documents phase. This procedure should only be used for rough thermal estimation during design development.

Calculating the Building Load Coefficient

The procedure consists of calculating several components of the Building Load Coefficient. It is based on Lower 48 experience and needs verification for Alaska. This coefficient is the additional heating that would be required to maintain a one degree Fahrenheit increase in the building inside temperature. For example, if the heat required to maintain the building at 70°F were determined to be 400,000 BTU/day, and the heat required to maintain the building at 71°F were determined to be 420,000 BTU/day, then the Building Load Coefficient is equal to the difference or 20,000 BTU/day for each °F (often expressed as 20,000 BTU/day•°F).

The procedure consists of adding together several estimated contributions of heat loss.

Start by making rough estimates of the combined area of all floors (ft^2) and the perimeter (the combined length in feet of all external walls at floor level). Then, either estimate the combined area of all east, west, and north windows, or use: nonsouth window area = (2/3) × (perimeter) × (ceiling) × (nonsouth window fraction). The nonsouth window fraction will normally be between 0.05 (for a situation with minimum window area) and 0.10 for a case with standard window area.

TABLE 13: REFLECTANCE VALUES FOR TWELVE REPRESENTATIVE WINTER LANDSCAPES	
Rural Areas	**Reflectance**
Fields with Snow Cover	
1. Field with wooded area in background	0.66-0.73
2. Open field (soil and dry grass), new road	0.61-0.70
3. Trees dispersed in field	0.62
Wooded Areas	
1. Conifer forest (with heavy snow cover)	0.61
2. Deciduous forest (with heavy snow cover)	0.72
Water	
1. Open water	0.16
2. Water covered with ice and snow	0.68
3. Partially open waterway (trees and houses in background)	0.43-0.66
Urban Areas	**Reflectance**
1. Commercial and institutional areas	0.16-0.38
2. Residential areas (dwelling and roadway)	0.21-0.45
3. Educational institution	0.36-0.42
4. Recreational area (park)	0.49

Next, estimate the south (solar) window area, being careful to **only include the net exposed portion of the window.** (The rest doesn't contribute to solar gain!) The derivation of the following formulas is based on a simplified use of the ASHRAE-type heat loss approach. All terms contain a factor of 24 to convert from BTU/hr•°F to BTU/day•°F. The terms L_w, L_g, L_f, and L_r are simply $24 \times U \times A$, where U is the U-value of the element (U is equal to $1/R$) and A is the area of the element. For glazings, the approximation is made that $U = 1.1 \times$ (number of glazings). For the perimeter and basement loss terms, the form is an approximation for rectangular slabs. So compute the following.

Walls:

$$L_w = 24 \times \frac{\text{wall area}}{\text{R - value of walls}}$$

where wall area = (perimeter) × (ceiling height) • (nonsouth window area) • (south window area)

Nonsouth Window:

$$L_g = 26 \times \frac{\text{nonsouth window area}}{\text{number of glazings}}$$

Perimeter (slab on grade):

$$L_p = 100 \times \frac{\text{length of foundation perimeter}}{(\text{R - value of perimeter insulation}) + 5}$$

Floor (over vented crawl space if present):

$$L_f = 24 \times \frac{\text{area of ground floor}}{\text{R - value of floor}}$$

Basement (heated basement or other fully earth-sheltered wall, including floor losses):

$$L_b = 256 \times \frac{\text{length of wall}}{(\text{R - value of wall insulation}) + 8}$$

Note: normally one of L_p, L_f, or L_b will apply.

Roof:

$$L_r = 24 \times \frac{\text{roof area}}{\text{R - value of roof}}$$

Infiltration:

L_i = (0.432 × (average air changes per hour) × (air density ratio) × (ceiling height) × (combined area of all floors)

Add the appropriate components to obtain the final BLC estimate, for example:

$$BLC = L_w + L_g + L_r + L_p + L_i$$

Note that the solar glazing is not included in the calculation of the Building Load Coefficient. This is done for two reasons:

1. The solar glazing would not be present in a nonsolar building, which is the principal basis of comparison.
2. The solar wall is a net energy gainer (**with shutters!**), not a loser, and to represent it as part of the load would be misleading.

Example Building Load Coefficient

Here is an example of a heat loss calculation using this method. The building is 1,000 square feet in floor area, well built (more insulation and better vapor barrier than average), 20 × 50 ft, slab on grade. The infiltration is 0.3 air changes per hour, and the walls have 7 inches of fiberglass in a 2 × 8-frame wall. The floor and perimeter are insulated with 2 inches of styrofoam. There are 60 ft^2 of nonsouth double-glazed windows, and the roof has 12-inch trusses with 11.0 inches of fiberglass. Ceilings are 8 feet high.

With this information, we can apply the previous equations. R-values are obtained from Appendix D.

Walls:

$$L_w = \frac{24(1{,}120)}{24}$$

$$L_w = 1{,}120 \text{ BTU}/°F$$

Nonsouth window:

$$L_g = \frac{(26 \times 60)}{1.24}$$

$$L_g = 848 \text{ BTU}/°F$$

Perimeter (slab on grade):

$$L_p = \frac{100 \times 140}{11.0 + 5} = 875$$

$$L_p = 875 \text{ BTU}/°F$$

(Only the perimeter heat loss applies since house is slab on grade.)

Roof:

$$L_r = 24 \times \frac{140}{37}$$

$$L_r = 908 \text{ BTU}/°F\bullet\text{day}$$

Infiltration:

$$L_i = 0.432 \times 0.3 \times 8{,}000$$

$$L_i = 1{,}037 \text{ BTU}/°F\bullet\text{day}$$

Combining all these factors, we get the Building Load Coefficient estimate in units of BTUs per °F•day.

$$\begin{aligned} L_w &= 1{,}120 \\ L_g &= 848 \\ L_p &= 875 \\ L_r &= 908 \\ L_i &= 1{,}037 \end{aligned}$$

$$BLC = 4{,}788 \text{ BTU}/°F\bullet\text{day}$$

This is a very good structure from a heat loss standpoint. Note, however, that this calculation neglects losses from south glazing. This assumption is critical for Alaska applications because of the need for shuttering the south facade when heat from the sun is not available. Obviously, there will be some heat loss from the south glazing, and experience will further define its importance.

The contributions to the Building Load Coefficient from conduction through the walls, nonsouth glazing, and roof are all significant and roughly comparable in magnitude. A large contribution is associated with the heating of infiltration air. This deserves special comment.

Infiltration

During design development, there is not enough information available to estimate the building infiltration. The minimum value that might be selected will depend on one of two considerations:

1. The minimum air change rate recommended for small buildings is ½ air change per hour (ACH). Below this, the building becomes stuffy, odors build up, and humidity accumulation due to water use within the building may be a problem. Buildings with lower infiltration rates than this (for example the Saskatchewan House, the Phillips house in Aachen, Germany, and the Denmark Zero-Energy House) often employed forced ventilation with heat recovery units. This approach is routinely used in large commercial buildings and it is now considered necessary for smaller structures (homes) in Alaska (Seifert, et al., 2002).
2. The air exchange rate associated with normal building construction is now typically ⅓ ACH or less. To achieve a low infiltration rate requires meticulous attention to sealing all cracks where air might leak into or out of the building. Some applications may require much higher air exchange rates as a matter of building code requirements. For example, a restaurant or lounge might require 4 ACH during periods of occupancy, and many other commercial applications might also require high values. Fresh air must be provided in some manner. Tight structures, in particular, offer the occupant the benefit of minimal unwanted air infiltration; hence, one may control the amount of exhaust and makeup air required by ventilation. Ventilation is necessary for the following reasons.

   a. To supply the proper amount of oxygen for the health of the occupants.
   b. To supply the proper amount of oxygen necessary for combustion if open-flame furnaces, fireplaces, etc., are on the premises.
   c. To dilute or eliminate excessive moisture in the air during the summer.
   d. To dilute or eliminate odors generated in the lavatory, locker-room, and kitchen.
   e. To dilute or remove the heat produced by internal sources during the summer.

In order to make energy-use projections for well-designed buildings, it is necessary to establish a reasonable level of ventilation. The level of ventilation will be determined for a 33 × 46 × 8.25 ft. test house with a total volume of 12,557 ft^3. For example, assume that the house is a total-electric residence (no open flames) and is occupied by four people. This is the simplest example, and virtually all real situations are worse than this!

A primary concern is the respiratory requirement for the occupants of a house. Generally humans need 20 percent oxygen in the air. They can exist with 15 percent oxygen, but combustion will not occur. Death for humans will result with only 5 percent to 7 percent oxygen. Table 14 indicates human oxygen and air requirements for various activities.

If the four occupants are assumed to engage in activities of the 50 ft^3/min level for 16 hours per day and the 0.21 ft^3/min level for 8 hours per day, the minimum ventilation level for the house would be 2,343 ft^3/day. This requires a complete air change to the house only once every 5.5 days.

Some recommendations require that the quantity of outdoor air introduced into spaces for normal respiratory and odor-control needs shall be no greater than 5 ft^3/min per person. With four occupants and 5 ft^3/min per occupant, the ventilation rate for a house is 29,240 ft^3 per day. This results in about 2.3 air changes per day.

Although there are no absolutes for determining correct ventilation levels

TABLE 14: OXYGEN AND AIR REQUIREMENTS OF HUMANS FOR VARIOUS ACTIVITIES

Activity	Oxygen Consumed ft^3/min	Air Required ft^3/min
Sleeping	0.0075	0.188
Sitting	0.0094	0.219
Standing	0.0113	0.251
Walking - 2 mph	0.0204	0.439
Walking - 4 mph	0.0376	0.815
Jogging	0.063	1.348
Maximum exertion	0.094-0.125	2.04-3.13

for odor and humidity control, some observations are useful. Data available for infiltration through window cracks and door openings indicate a ventilation level in a relatively tight house of approximately two air changes per day. Actual houses that fit these conditions show this is the minimal level for elimination of lingering odors, especially pungent cooking odors. The ventilation rate of two air changes per day is just below the code minimum of 2.33. A residence should have no less than two air changes per day. Until sufficient experience is gained in the ventilation of these houses, each should be analyzed before construction, and provisions should be made for increasing or decreasing ventilation as necessary. (See AHFC, Alaska State Thermal Efficiency Standards.)

Where open flames, including fireplaces, are present in well-sealed homes, increased makeup air and ventilation must be provided. For purposes of energy conservation, combustion air should be ducted to furnaces or fireplaces from outside. As an alternate solution, delivery of heated makeup air (incoming fresh air) to the proximity of the fireplace may be considered. Ventilation may also be required for the removal of excess internal heat.